

Patent Application of Michael M. Schechter for  
"Operating a Vehicle with Braking Energy Recovery"

CLAIMS--I claim:

1. A method of operating a wheeled vehicle, said method comprising the steps of:
  - (a) providing an engine mounted in said vehicle and coupled to at least one vehicle wheel for its propulsion and braking, said engine including at least two cylinders and a cylinder chamber within each of said at least two cylinders,
  - (b) providing an air-reservoir means mounted in said vehicle and connected to said engine for receiving, storage, and discharge of compressed air,
  - (c) operating said engine in a compression-braking mode driven by a vehicle momentum in response to a demand for a vehicle braking force, when said vehicle is in motion and a vehicle braking force is needed, by repeatedly performing a compression-braking cycle, during which air is received from outside atmosphere into at least one of said at least two cylinders, compressed there, transferred to another at least one of said at least two cylinders, subjected to at least one additional compression, and displaced into said air-reservoir means for storage therein,  
whereby energy of the vehicle motion is transformed into energy of compressed air stored in said air-reservoir means,  
whereby said at least one additional compression increases said vehicle braking force, and whereby an increase in temperature of said air, associated with said at least one additional compression, reduces the mass of air required to absorb said energy of vehicle motion and reduces the required volume of said air-reservoir means,  
and
  - (d) operating said engine in a prime mover mode propelling said vehicle when vehicle propulsion force is needed, said prime mover mode including:
    - (A) operating said engine in a mode selected from a variety of propulsion modes comprising:
      - (1) a first propulsion mode including repeated performance of a multi-stage air-motor cycle, during which a charge of compressed air is received from said air-reservoir means, subjected to at least two successive stages of expansion in said at least two cylinders, and exhausted into said outside atmosphere, whereby said vehicle is propelled without any fuel being consumed,

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- (2) a second propulsion mode comprising:
- repeated performance of a two-stroke air-motor cycle in at least one of said at least two cylinders, said two-stroke air-motor cycle including a first stage of expansion of a compressed-air charge received from said air-reservoir means into said cylinder chamber and expulsion of said compressed-air charge from said cylinder chamber, and
  - repeated performance of a hybrid four-stroke cycle in another at least one of said at least two cylinders, said hybrid four-stroke cycle comprising two power strokes:
    - a first power stroke including a second stage of expansion of said compressed-air charge during a first volume-increasing stroke, and
    - a second power stroke including expansion of combustion gas, produced as a result of fuel combustion, in said cylinder chamber during a second volume-increasing stroke, whereby work performed during said first power stroke is added to work performed during said second power stroke,
- (3) a third propulsion mode comprising:
- repeated performance of a two-stroke air-motor cycle in at least one of said at least two cylinders, said two-stroke air-motor cycle including a first stage of expansion of a compressed-air charge received from said air-reservoir means into said cylinder chamber and expulsion of said compressed-air charge from said cylinder chamber, and
  - repeated performance of a hybrid two-stroke internal-combustion cycle in another at least one of said at least two cylinders, during which said compressed-air charge is received into said cylinder chamber and used for combustion during the same cycle, whereby energy of said compressed-air charge supplements the energy released in combustion,
- (4) a fourth propulsion mode including operating said engine in a conventional internal-combustion mode receiving air from said outside atmosphere, and
- (B) changing said engine operation from one propulsion mode to another one selected from said variety of propulsion modes.

2. The method of claim 1 further including the steps of:
  - (a) providing a head mounted to said at least two cylinders,
  - (b) providing a piston within each said cylinder chamber, with the piston to head and cylinder relationship being such that the volume of said cylinder chamber shrinks during a volume-decreasing stroke, when said piston moves toward said head, and expands during a volume-increasing stroke, when said piston moves away from said head,
  - (c) providing a gas exchange controlling means for accommodating gas flow into and out of said cylinder chamber,
  - (d) providing a fuel delivery means for selectively and variably adding fuel to the air intended for participation in combustion in said engine in timed relation to said engine operation,
  - (e) providing means for allowing a vehicle driver to perform vehicle control functions including:
    - (1) selectively demanding a vehicle braking force,
    - (2) selectively demanding a vehicle propulsion force,
    - (3) selectively demanding a change in magnitude of said vehicle braking force, and
    - (4) selectively demanding a change in magnitude of said vehicle propulsion force,
  - (f) providing a control means for controlling the operation of said engine and said vehicle in response to driver's demands and in accordance with a control program incorporated in said control means.
3. The method of claim 1 wherein said variety of propulsion modes further includes:
  - (a) a fifth propulsion mode including repeated performance of a two-stroke air-motor cycle in each of said at least two cylinders, during which a charge of compressed air is received from said air-reservoir means, subjected to expansion in said cylinder chamber, and exhausted into said outside atmosphere, whereby said vehicle is propelled without any fuel being consumed,
  - (b) a sixth propulsion mode including repeated performance of a hybrid four-stroke cycle in each of said at least two cylinders, said hybrid four-stroke cycle comprising two power strokes:

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- (1) a first power stroke including expansion of a compressed-air charge, received from said air-reservoir means, in said cylinder chamber during a first volume-increasing stroke, and
  - (2) a second power stroke including expansion of combustion gas, produced as a result of fuel combustion, in said cylinder chamber during a second volume-increasing stroke,
- whereby work performed during said first power stroke is added to work performed during said second power stroke, and
- (c) a seventh propulsion mode including repeated performance of a hybrid two-stroke internal combustion cycle in each of said at least two cylinders, during which a compressed-air charge is received into said cylinder chamber from said air-reservoir means and used for combustion during the same cycle, whereby energy of said compressed-air charge supplements the energy released in combustion.
4. The method of claim 1 wherein said variety of propulsion modes further comprises a hybrid propulsion mode including operating some of said engine cylinders in a conventional internal-combustion mode, in which air is received from said outside atmosphere into said some of said engine cylinders and used for combustion therein, and operating the rest of said engine cylinders in a compressor mode, in which air is received from said outside atmosphere, subjected to at least two successive stages of compression in said rest of said engine cylinders, and displaced into said air-reservoir means, whereby the engine cylinders operating in said conventional internal-combustion mode propel said vehicle and drive the engine cylinders operating in said compressor mode, and whereby said air-reservoir means can be recharged with compressed air whenever the power required to propel said vehicle is less than the maximum power of said engine.
5. The method of claim 1 further comprising the steps of providing at least one friction brake and activating said at least one friction brake when operating said engine in said compression-braking mode, whereby the braking force produced by said at least one friction brake supplements the braking force produced by said engine.

6. The method of claim 1 further comprising the steps of providing a transmission means for selectively coupling said engine to said at least one vehicle wheel with a variable transmission ratio, and responding to a demand for a change in magnitude of said vehicle braking force by selectively changing said transmission ratio.
7. The method of claim 2 further comprising the steps of:
  - (a) providing a heating jacket surrounding said air-reservoir means, and
  - (b) flowing exhaust gas through said heating jacket during operation of said engine, whereby escape of heat from the air in said air-reservoir means is prevented.
8. The method of claim 7 further comprising the steps of:
  - (a) providing a gas flow control means for controlling flow of exhaust gas through said heating jacket,
  - (b) providing a temperature sensor for measuring temperature of air inside said air-reservoir means,
  - (c) providing said control means with information from said temperature sensor and with ability to cooperate with said gas flow control means to control said flow of exhaust gas through said heating jacket, and
  - (d) using said control means to control said flow of exhaust gas in a manner which assures that said temperature of air inside said air-reservoir means is maintained within a predetermined range.
9. The method of claim 2 further comprising the step of responding to said demand for a change in magnitude of said vehicle braking force, or to said demand for a change in magnitude of said vehicle propulsion force, by making changes in timing of operation of said gas exchange controlling means.
10. The method of claim 2 wherein the step of providing an engine including at least two cylinders further includes the steps of:
  - (a) providing at least one primary cylinder for performing a first stage of air compression when said engine operates in said compression-braking mode, and for performing a

second stage of air expansion when said engine operates in said first, second, and third propulsion modes, and

- (b) providing at least one secondary cylinder for performing a second stage of air compression when said engine operates in said compression-braking mode, and for performing a first stage of air expansion when said engine operates in said first, second, and third propulsion modes.

11. The method of claim 10 wherein the step of providing said gas exchange controlling means further comprises the steps of:

- (a) providing a manifold means for accommodating gas flow into and out of said engine cylinders, said manifold means including:
  - (1) at least one low-pressure manifold connected to said outside atmosphere,
  - (2) at least one medium-pressure manifold,
  - (3) at least one high-pressure manifold connected to said air-reservoir means, and
  - (4) at least one exhaust manifold connected to said outside atmosphere,
- and
- (b) providing valves for selectively, variably, and alternatively connecting said cylinder chamber to said manifold means in timed relation to said engine operation.

12. The method of claim 11 wherein said valves include at least one valve that can operate with multiple valve-opening events during an engine revolution, said valve-opening events including:

- (a) a first valve-opening event that takes place during said volume-decreasing stroke and accommodates flow of air out of said cylinder chamber, and
- (b) a second valve-opening event that takes place during said volume-increasing stroke and accommodates flow of air into said cylinder chamber,

whereby the net flow of air, during said engine revolution, is out of said cylinder chamber when volume of air flowing out of said cylinder chamber during said first valve-opening event is greater than volume of air flowing into said cylinder chamber during said second valve-opening event,

whereby the net flow of air, during said engine revolution, is into said cylinder chamber when volume of air flowing out of said cylinder chamber during said first valve-opening event is smaller than volume of air flowing into said cylinder chamber during said second valve-opening event, and

whereby a very small volume of airflow out of or into said cylinder chamber can be achieved without resorting to excessively short duration of valve-opening event.

13. The method of claim 11 wherein:

(a) the step of operating said engine in said compression-braking mode further comprises the steps of:

(1) receiving air from said outside atmosphere through at least one of said valves into said cylinder chamber in at least one of said at least two cylinders, compressing it in said at least one of said at least two cylinders, and displacing it from said at least one of said at least two cylinders through another at least one of said valves into said at least one medium-pressure manifold, and

(2) receiving air from said at least one medium-pressure manifold through at least one of said valves into said cylinder chamber in another at least one of said at least two cylinders, compressing it in said another at least one of said at least two cylinders, and displacing it from said another at least one of said at least two cylinders through another at least one of said valves into said air-reservoir means,

(b) operation of said engine in said first propulsion mode further comprises the steps of:

(1) receiving compressed air from said air-reservoir means through at least one of said valves into said cylinder chamber in at least one of said at least two cylinders, expanding it in said at least one of said at least two cylinders, and displacing it from said at least one of said at least two cylinders through another at least one of said valves into said at least one medium-pressure manifold, and

(2) receiving air from said at least one medium-pressure manifold through at least one of said valves into said cylinder chamber in another at least one of said at least two cylinders, expanding it in said another at least one of said at least two cylinders, and displacing it from said another at least one of said at least two cylinders through another at least one of said valves into said outside atmosphere,

(c) operation of said engine in said second propulsion mode further comprises the steps of:

- (1) receiving compressed air from said air-reservoir means through at least one of said valves into said cylinder chamber in at least one of said at least two cylinders, expanding it in said at least one of said at least two cylinders, and displacing it from said at least one of said at least two cylinders through another at least one of said valves into said at least one medium-pressure manifold, and
- (2) receiving air from said at least one medium-pressure manifold through at least one of said valves into said cylinder chamber in another at least one of said at least two cylinders, expanding it and using it for combustion in a four-stroke internal-combustion cycle performed in said another at least one of said at least two cylinders, and displacing combustion gas from said another at least one of said at least two cylinders through another at least one of said valves into said outside atmosphere, and

(d) operation of said engine in said third propulsion mode further comprises the steps of:

- (1) receiving compressed air from said air-reservoir means through at least one of said valves into said cylinder chamber in at least one of said at least two cylinders, expanding it in said at least one of said at least two cylinders, and displacing it from said at least one of said at least two cylinders through another at least one of said valves into said at least one medium-pressure manifold, and
- (2) receiving air from said at least one medium-pressure manifold through at least one of said valves into said cylinder chamber in another at least one of said at least two cylinders, using it for combustion in a two-stroke internal-combustion cycle performed in said another at least one of said at least two cylinders, and displacing combustion gas from said another at least one of said at least two cylinders through another at least one of said valves into said outside atmosphere.

14. The method of claim 11 wherein the step of providing said valves further comprises the steps of:

- (a) providing at least one first valve for selectively and variably connecting said cylinder chamber to said at least one low-pressure manifold,



- (b) providing at least one second valve for selectively and variably connecting said cylinder chamber to said at least one medium-pressure manifold,
  - (c) providing at least one third valve for selectively and variably connecting said cylinder chamber to said at least one high-pressure manifold, and
  - (d) providing at least one fourth valve for selectively connecting said cylinder chamber to said at least one exhaust manifold.
15. The method of claim 14 wherein a first air compression performed in said at least one primary cylinder, during operation of said engine in said compression-braking mode, further comprises, during each two-stroke cycle, the steps of:
- (a) deactivating said fuel delivery means,
  - (b) deactivating said at least one fourth valve,
  - (c) deactivating said at least one third valve,
  - (d) expanding the residual compressed air during a first part of said volume-increasing stroke,
  - (e) variably opening said at least one first valve,
  - (f) receiving air from said at least one low-pressure manifold into said cylinder chamber during a second part of said volume-increasing stroke,
  - (g) variably closing said at least one first valve,
  - (h) compressing said air in said cylinder chamber during a first part of said volume-decreasing stroke,
  - (i) variably opening said at least one second valve,
  - (j) substantially displacing the compressed air from said cylinder chamber into said at least one medium-pressure manifold during a second part of said volume-decreasing stroke, and
  - (k) variably closing said at least one second valve,
- and wherein a second air compression performed in said at least one secondary cylinder, during operation of said engine in said compression-braking mode, further comprises, during each two-stroke cycle, the steps of:
- (a) deactivating said fuel delivery means,
  - (b) deactivating said at least one fourth valve,

- (c) deactivating said at least one first valve,
  - (d) expanding the residual compressed air during a first part of said volume-increasing stroke,
  - (e) variably opening said at least one second valve,
  - (f) receiving air from said at least one medium-pressure manifold into said cylinder chamber during a second part of said volume-increasing stroke,
  - (g) variably closing said at least one second valve,
  - (h) compressing said air in said cylinder chamber during a first part of said volume-decreasing stroke,
  - (i) variably opening said at least one third valve,
  - (j) substantially displacing the compressed air from said cylinder chamber into said at least one high-pressure manifold, and
  - (k) variably closing said at least one third valve.
16. The method of claim 14 wherein a first stage of air expansion performed in said at least one secondary cylinder, during operation of said engine in said first propulsion mode, further comprises, during each two-stroke cycle, the steps of:
- (a) deactivating said fuel delivery means,
  - (b) deactivating said at least one fourth valve,
  - (c) deactivating said at least one first valve,
  - (d) variably opening said at least one third valve,
  - (e) receiving compressed air from said at least one high-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,
  - (f) variably closing said at least one third valve,
  - (g) expanding said compressed air in said cylinder chamber during a second part of said volume-increasing stroke,
  - (h) variably opening said at least one second valve,
  - (i) substantially displacing the air from said cylinder chamber into said at least one medium-pressure manifold during said volume-decreasing stroke, and
  - (j) variably closing said at least one second valve,

and wherein a second stage of air expansion performed in said at least one primary cylinder, during operation of said engine in said first propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said fuel delivery means,
- (b) deactivating said at least one first valve,
- (c) deactivating said at least one third valve,
- (d) variably opening said at least one second valve,
- (e) receiving air from said at least one medium-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,
- (f) variably closing said at least one second valve,
- (g) expanding said air in said cylinder chamber during a second part of said volume-increasing stroke,
- (h) variably opening said at least one fourth valve,
- (i) substantially displacing the air from said cylinder chamber into said at least one exhaust manifold during said volume-decreasing stroke, and
- (j) variably closing said at least one fourth valve.

17. The method of claim 14 wherein said performance of a two-stroke air-motor cycle in said at least one secondary cylinder, during operation of said engine in said second propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said fuel delivery means,
- (b) deactivating said at least one fourth valve,
- (c) deactivating said at least one first valve,
- (d) variably opening said at least one third valve,
- (e) receiving compressed air from said at least one high-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,
- (f) variably closing said at least one third valve,
- (g) expanding said compressed air in said cylinder chamber during a second part of said volume-increasing stroke,
- (h) variably opening said at least one second valve,

- (i) substantially displacing the air from said cylinder chamber into said at least one medium-pressure manifold during said volume-decreasing stroke, and
  - (j) variably closing said at least one second valve,
- and wherein said performance of said hybrid four-stroke cycle in said at least one primary cylinder, during operation of said engine in said second propulsion mode, further comprises, during each four-stroke cycle, the steps of:
- (a) deactivating said at least one first valve,
  - (b) deactivating said at least one third valve,
  - (c) variably opening said at least one second valve,
  - (d) receiving air into said cylinder chamber from said at least one medium-pressure manifold during a first part of a first volume-increasing stroke,
  - (e) variably closing said at least one second valve,
  - (f) expanding said air in said cylinder chamber during a second part of said first volume-increasing stroke,
  - (g) compressing said air in said cylinder chamber during a first volume-decreasing stroke,
  - (h) adding fuel to said air,
  - (i) initiating combustion of said fuel in said cylinder chamber, whereby said fuel and said air are converted into a combustion gas,
  - (j) expanding said combustion gas in said cylinder chamber during a second volume-increasing stroke,
  - (k) variably opening said at least one fourth valve,
  - (l) substantially expelling said combustion gas from said cylinder chamber into said at least one exhaust manifold during a first part of a second volume-decreasing stroke,
  - (m) variably closing said at least one fourth valve, and
  - (n) trapping the residual combustion gas remaining in said cylinder chamber during a second part of said second volume-decreasing stroke,
- whereby work performed by said combustion gas during said second volume-increasing stroke is supplemented by work performed by said air during said first volume-increasing stroke, and whereby trapping said residual gas in said cylinder chamber during said second part of said second volume-decreasing stroke contributes to reduction in harmful nitrogen oxide emission.

18. The method of claim 14 wherein said performance of a two-stroke air-motor cycle in said at least one secondary cylinder, during operation of said engine in said third propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said fuel delivery means,
- (b) deactivating said at least one fourth valve,
- (c) deactivating said at least one first valve,
- (d) variably opening said at least one third valve,
- (e) receiving compressed air from said at least one high-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,
- (f) variably closing said at least one third valve,
- (g) expanding said compressed air in said cylinder chamber during a second part of said volume-increasing stroke,
- (h) variably opening said at least one second valve,
- (i) substantially displacing the air from said cylinder chamber into said at least one medium-pressure manifold during said volume-decreasing stroke, and
- (j) variably closing said at least one second valve,

and wherein said performance of a hybrid two-stroke internal-combustion cycle in said at least one primary cylinder, during operation of said engine in said third propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said at least one third valve,
- (b) deactivating said at least one first valve,
- (c) variably opening said at least one second valve,
- (d) receiving compressed air into said cylinder chamber from said at least one medium-pressure manifold during a second part of said volume-decreasing stroke,
- (e) variably closing said at least one second valve,
- (f) compressing said compressed air and residual combustion gas in said cylinder chamber during a third part of said volume-decreasing stroke,
- (g) adding fuel to the mixture of said compressed air and said residual combustion gas in said cylinder chamber,

- (h) initiating combustion of said fuel in said cylinder chamber, whereby said fuel and said compressed air are converted into a combustion gas,
  - (i) expanding said combustion gas in said cylinder chamber during said volume-increasing stroke,
  - (j) variably opening said at least one fourth valve,
  - (k) substantially expelling said combustion gas from said cylinder chamber into said at least one exhaust manifold during a first part of said volume-decreasing stroke, and
  - (l) variably closing said at least one fourth valve,
- whereby receiving of said compressed air into said cylinder chamber from said at least one medium-pressure manifold reduces the amount of compression work required.

19. The method of claim 14 wherein the operation of said engine in said fourth propulsion mode further includes the steps of:

- (a) deactivating said at least one second valve in all engine cylinders,
- (b) deactivating said at least one third valve in all engine cylinders, and
- (c) operating said engine as a conventional internal-combustion engine receiving air from said at least one low-pressure manifold through said at least one first valve into said cylinder chamber and discharging exhaust gas from said cylinder chamber through said at least one fourth valve into said at least one exhaust manifold.

20. The method of claim 11 wherein the step of providing said valves further comprises the steps of:

- (a) providing at least one first air valve for selectively and variably connecting said cylinder chamber either to said at least one low-pressure manifold or to said at least one high-pressure manifold,
- (b) providing at least one second air valve for selectively and variably connecting said cylinder chamber either to said at least one low-pressure manifold or to said at least one medium-pressure manifold,
- (c) providing at least one exhaust valve for selectively connecting said cylinder chamber to said at least one exhaust manifold, and

- (d) providing a switching means for setting an arrangement of said gas exchange controlling means into a configuration selected from a variety of configurations, and switching said arrangement from one configuration to another in accordance with said program incorporated in said control means, said variety of configurations including:
    - (1) a first switching configuration wherein said at least one low-pressure manifold is connected to said at least one first air valve in said at least one primary cylinder, said at least one medium-pressure manifold is connected to said at least one second air valve in said at least one primary cylinder and to said at least one second air valve in said at least one secondary cylinder, and said at least one high-pressure manifold is connected to said at least one first air valve in said at least one secondary cylinder, and
    - (2) a second switching configuration wherein said medium-pressure and high-pressure manifolds are disconnected from the valves in said primary and secondary cylinders, and said at least one low-pressure manifold is connected to said first and second air valves in said at least one primary cylinder and to said first and second air valves in said at least one secondary cylinder.
21. The method of claim 20 wherein said arrangement of said gas exchange controlling means is set into said second switching configuration if said engine operates in said fourth propulsion mode, and is set into said first switching configuration if said engine operates in any one of the following modes:
- (a) compression-braking mode,
  - (b) first propulsion mode,
  - (c) second propulsion mode, and
  - (d) third propulsion mode.
22. The method of claim 21 wherein a first air compression performed in said at least one primary cylinder, during operation of said engine in said compression-braking mode, further comprises, during each two-stroke cycle, the steps of:
- (a) deactivating said fuel delivery means,
  - (b) deactivating said at least one exhaust valve,

- (c) expanding the residual compressed air during a first part of said volume-increasing stroke,
  - (d) variably opening said at least one first air valve,
  - (e) receiving air from said at least one low-pressure manifold into said cylinder chamber during a second part of said volume-increasing stroke,
  - (f) variably closing said at least one first air valve,
  - (g) compressing said air in said cylinder chamber during a first part of said volume-decreasing stroke,
  - (h) variably opening said at least one second air valve,
  - (i) substantially displacing the compressed air from said cylinder chamber into said at least one medium-pressure manifold during a second part of said volume-decreasing stroke, and
  - (j) variably closing said at least one second air valve,
- and wherein a second air compression performed in said at least one secondary cylinder, during operation of said engine in said compression-braking mode, further comprises, during each two-stroke cycle, the steps of:
- (a) deactivating said fuel delivery means,
  - (b) deactivating said at least one exhaust valve,
  - (c) expanding the residual compressed air during a first part of said volume-increasing stroke,
  - (d) variably opening said at least one second air valve,
  - (e) receiving air from said at least one medium-pressure manifold into said cylinder chamber during a second part of said volume-increasing stroke,
  - (f) variably closing said at least one second air valve,
  - (g) compressing said air in said cylinder chamber during a first part of said volume-decreasing stroke,
  - (h) variably opening said at least one first air valve,
  - (i) substantially displacing the compressed air from said cylinder chamber into said at least one high-pressure manifold, and
  - (j) variably closing said at least one first air valve.



23. The method of claim 21 wherein a first stage of air expansion performed in said at least one secondary cylinder, during operation of said engine in said first propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said fuel delivery means,
- (b) deactivating said at least one exhaust valve,
- (c) variably opening said at least one first air valve,
- (d) receiving compressed air from said at least one high-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,
- (e) variably closing said at least one first air valve,
- (f) expanding said compressed air in said cylinder chamber during a second part of said volume-increasing stroke,
- (g) variably opening said at least one second air valve,
- (h) substantially displacing the air from said cylinder chamber into said at least one medium-pressure manifold during said volume-decreasing stroke, and
- (i) variably closing said at least one second air valve,

and wherein a second stage of air expansion performed in said at least one primary cylinder, during operation of said engine in said first propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said fuel delivery means,
- (b) deactivating said at least one first air valve,
- (c) variably opening said at least one second air valve,
- (d) receiving air from said at least one medium-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,
- (e) variably closing said at least one second air valve,
- (f) expanding said air in said cylinder chamber during a second part of said volume-increasing stroke,
- (g) variably opening said at least one exhaust valve,
- (h) substantially displacing the air from said cylinder chamber into said at least one exhaust manifold during said volume-decreasing stroke, and
- (i) variably closing said at least one exhaust valve.

24. The method of claim 21 wherein said performance of a two-stroke air-motor cycle in said at least one secondary cylinder, during operation of said engine in said second propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said fuel delivery means,
- (b) deactivating said at least one exhaust valve,
- (c) variably opening said at least one first air valve,
- (d) receiving compressed air from said at least one high-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,
- (e) variably closing said at least one first air valve,
- (f) expanding said compressed air in said cylinder chamber during a second part of said volume-increasing stroke,
- (g) variably opening said at least one second air valve,
- (h) substantially displacing the air from said cylinder chamber into said at least one medium-pressure manifold during said volume-decreasing stroke, and
- (i) variably closing said at least one second air valve,

and wherein said performance of a hybrid four-stroke cycle in said at least one primary cylinder, during operation of said engine in said second propulsion mode, further comprises, during each four-stroke cycle, the steps of:

- (a) deactivating said at least one first air valve,
- (b) variably opening said at least one second air valve,
- (c) receiving air into said cylinder chamber from said at least one medium-pressure manifold during a first part of a first volume-increasing stroke,
- (d) variably closing said at least one second air valve,
- (e) expanding said air in said cylinder chamber during a second part of said first volume-increasing stroke,
- (f) compressing said air in said cylinder chamber during a first volume-decreasing stroke,
- (g) adding fuel to said air,
- (h) initiating combustion of said fuel in said cylinder chamber, whereby said fuel and said air are converted into a combustion gas,
- (i) expanding said combustion gas in said cylinder chamber during a second volume-increasing stroke,

- (j) variably opening said at least one exhaust valve,
  - (k) substantially expelling said combustion gas from said cylinder chamber into said at least one exhaust manifold during a first part of a second volume-decreasing stroke,
  - (l) variably closing said at least one exhaust valve, and
  - (m) trapping the residual combustion gas remaining in said cylinder chamber during a second part of said second volume-decreasing stroke,
- whereby work performed by said combustion gas during said second volume-increasing stroke is supplemented by work performed by said air during said first volume-increasing stroke, and whereby trapping said residual gas in said cylinder chamber during said second part of said second volume-decreasing stroke contributes to reduction in harmful nitrogen oxide emission.

25. The method of claim 21 wherein said performance of a two-stroke air-motor cycle in said at least one secondary cylinder, during operation of said engine in said third propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said fuel delivery means,
- (b) deactivating said at least one exhaust valve,
- (c) variably opening said at least one first air valve,
- (d) receiving compressed air from said at least one high-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,
- (e) variably closing said at least one first air valve,
- (f) expanding said compressed air in said cylinder chamber during a second part of said volume-increasing stroke,
- (g) variably opening said at least one second air valve,
- (h) substantially displacing the air from said cylinder chamber into said at least one medium-pressure manifold during said volume-decreasing stroke, and

(i) variably closing said at least one second air valve,

and wherein said performance of a hybrid two-stroke internal-combustion cycle in said at least one primary cylinder, during operation of said engine in said third propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said at least one first air valve,

- (b) variably opening said at least one second air valve,
  - (c) receiving compressed air into said cylinder chamber from said at least one medium-pressure manifold during a second part of said volume-decreasing stroke,
  - (d) variably closing said at least one second air valve,
  - (e) compressing said compressed air and residual combustion gas in said cylinder chamber during a third part of said volume-decreasing stroke,
  - (f) adding fuel to the mixture of said compressed air and said residual combustion gas in said cylinder chamber,
  - (g) initiating combustion of said fuel in said cylinder chamber, whereby said fuel and said compressed air are converted into a combustion gas,
  - (h) expanding said combustion gas in said cylinder chamber during said volume-increasing stroke,
  - (i) variably opening said at least one exhaust valve,
  - (j) substantially expelling said combustion gas from said cylinder chamber into said at least one exhaust manifold during a first part of said volume-decreasing stroke, and
  - (k) variably closing said at least one exhaust valve,
- whereby receiving of said compressed air into said cylinder chamber from said at least one medium-pressure manifold reduces the amount of compression work required.

26. The method of claim 21 wherein the operation of said engine in said fourth propulsion mode further includes the step of operating said engine as a conventional internal-combustion engine receiving air from said at least one low-pressure manifold through said at least one first air valve and through said at least one second air valve into said cylinder chamber and discharging exhaust gas from said cylinder chamber through said at least one exhaust valve into said at least one exhaust manifold.

27. The method of claim 11 wherein the step of providing said valves further comprises the steps of:

- (a) providing at least one first engine valve for selectively and variably connecting said cylinder chamber either to said at least one low-pressure manifold, or to said at least one medium-pressure manifold, or to said at least one high-pressure manifold,

- (b) providing at least one second engine valve for selectively and variably connecting said cylinder chamber either to said at least one medium-pressure manifold or to said at least one exhaust manifold, and
  - (c) providing a switching means for setting an arrangement of said gas exchange controlling means into a configuration selected from a variety of configurations, and switching said arrangement from one configuration to another in accordance with said program incorporated in said control means, said variety of configurations including:
    - (1) a first switching configuration wherein said at least one low-pressure manifold is connected to said at least one first engine valve in said at least one primary cylinder, said at least one medium-pressure manifold is connected to said at least one second engine valve in said at least one primary cylinder and to said at least one second engine valve in said at least one secondary cylinder, said at least one high-pressure manifold is connected to said at least one first engine valve in said at least one secondary cylinder, and said at least one exhaust manifold is disconnected from the valves in said primary and secondary cylinders,
    - (2) a second switching configuration wherein said at least one low-pressure manifold is disconnected from the valves in said primary and secondary cylinders, said at least one medium-pressure manifold is connected to said first engine valve in said primary cylinder and to said second engine valve in said secondary cylinder, said at least one high-pressure manifold is connected to said first engine valve in said secondary cylinder, and said at least one exhaust manifold is connected to said second engine valve in said primary cylinder, and
    - (3) a third switching configuration wherein said medium-pressure and high-pressure manifolds are disconnected from the valves in said primary and secondary cylinders, said at least one low-pressure manifold is connected to said first engine valves in said primary and secondary cylinders, and said at least one exhaust manifold is connected to said second engine valves in said primary and secondary cylinders.
28. The method of claim 27 wherein said arrangement of said gas exchange controlling means is set into:

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- (a) said first switching configuration if said engine operates in said compression-braking mode,
  - (b) said second switching configuration if said engine operates in any one of the following modes:
    - (1) first propulsion mode,
    - (2) second propulsion mode, and
    - (3) third propulsion mode, and
  - (c) said third switching configuration if said engine operates in said fourth propulsion mode.
29. The method of claim 28 wherein a first air compression performed in said at least one primary cylinder, during operation of said engine in said compression-braking mode, further comprises, during each two-stroke cycle, the steps of:
- (a) deactivating said fuel delivery means,
  - (b) expanding the residual compressed air during a first part of said volume-increasing stroke,
  - (c) variably opening said at least one first engine valve,
  - (d) receiving air from said at least one low-pressure manifold into said cylinder chamber during a second part of said volume-increasing stroke,
  - (e) variably closing said at least one first engine valve,
  - (f) compressing said air in said cylinder chamber during a first part of said volume-decreasing stroke,
  - (g) variably opening said at least one second engine valve,
  - (h) substantially displacing the compressed air from said cylinder chamber into said at least one medium-pressure manifold during a second part of said volume-decreasing stroke, and
  - (i) variably closing said at least one second engine valve,
- and wherein a second air compression performed in said at least one secondary cylinder, during operation of said engine in said compression-braking mode, further comprises, during each two-stroke cycle, the steps of:
- (a) deactivating said fuel delivery means,

- (b) expanding the residual compressed air during a first part of said volume-increasing stroke,
  - (c) variably opening said at least one second engine valve,
  - (d) receiving air from said at least one medium-pressure manifold into said cylinder chamber during a second part of said volume-increasing stroke,
  - (e) variably closing said at least one second engine valve,
  - (f) compressing said air in said cylinder chamber during a first part of said volume-decreasing stroke,
  - (g) variably opening said at least one first engine valve,
  - (h) substantially displacing the compressed air from said cylinder chamber into said at least one high-pressure manifold, and
  - (i) variably closing said at least one first engine valve.
30. The method of claim 28 wherein a first stage of air expansion performed in said at least one secondary cylinder, during operation of said engine in said first propulsion mode, further comprises, during each two-stroke cycle, the steps of:
- (a) deactivating said fuel delivery means,
  - (b) variably opening said at least one first engine valve,
  - (c) receiving compressed air from said at least one high-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,
  - (d) variably closing said at least one first engine valve,
  - (e) expanding said compressed air in said cylinder chamber during a second part of said volume-increasing stroke,
  - (f) variably opening said at least one second engine valve,
  - (g) substantially displacing the air from said cylinder chamber into said at least one medium-pressure manifold during said volume-decreasing stroke, and
  - (h) variably closing said at least one second engine valve,
- and wherein a second stage of air expansion performed in said at least one primary cylinder, during operation of said engine in said first propulsion mode, further comprises, during each two-stroke cycle, the steps of:
- (a) deactivating said fuel delivery means,

- (b) variably opening said at least one first engine valve,
- (c) receiving air from said at least one medium-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,
- (d) variably closing said at least one first engine valve,
- (e) expanding said air in said cylinder chamber during a second part of said volume-increasing stroke,
- (f) variably opening said at least one second engine valve,
- (g) substantially displacing the air from said cylinder chamber into said at least one exhaust manifold during said volume-decreasing stroke, and
- (h) variably closing said at least one second engine valve.

31. The method of claim 28 wherein said performance of a two-stroke air-motor cycle in said at least one secondary cylinder, during operation of said engine in said second propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said fuel delivery means,
- (b) variably opening said at least one first engine valve,
- (c) receiving compressed air from said at least one high-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,
- (d) variably closing said at least one first engine valve,
- (e) expanding said compressed air in said cylinder chamber during a second part of said volume-increasing stroke,
- (f) variably opening said at least one second engine valve,
- (g) substantially displacing the air from said cylinder chamber into said at least one medium-pressure manifold during said volume-decreasing stroke, and
- (h) variably closing said at least one second engine valve,

and wherein said performance of a hybrid four-stroke cycle in said at least one primary cylinder, during operation of said engine in said second propulsion mode, further comprises, during each four-stroke cycle, the steps of:

- (a) variably opening said at least one first engine valve,
- (b) receiving air into said cylinder chamber from said at least one medium-pressure manifold during a first part of a first volume-increasing stroke,



- (c) variably closing said at least one first engine valve,
- (d) expanding said air in said cylinder chamber during a second part of said first volume-increasing stroke,
- (e) compressing said air in said cylinder chamber during a first volume-decreasing stroke,
- (f) adding fuel to said air,
- (g) initiating combustion of said fuel in said cylinder chamber, whereby said fuel and said air are converted into a combustion gas,
- (h) expanding said combustion gas in said cylinder chamber during a second volume-increasing stroke,
- (i) variably opening said at least one second engine valve,
- (j) substantially expelling said combustion gas from said cylinder chamber into said at least one exhaust manifold during a first part of a second volume-decreasing stroke,
- (k) variably closing said at least one second engine valve, and
- (l) trapping the residual combustion gas remaining in said cylinder chamber during a second part of said second volume-decreasing stroke,

whereby work performed by said combustion gas during said second volume-increasing stroke is supplemented by work performed by said air during said first volume-increasing stroke, and whereby trapping said residual gas in said cylinder chamber during said second part of said second volume-decreasing stroke contributes to reduction in harmful nitrogen oxide emission.

32. The method of claim 28 wherein said performance of a two-stroke air-motor cycle in said at least one secondary cylinder, during operation of said engine in said third propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said fuel delivery means,
- (b) variably opening said at least one first engine valve,
- (c) receiving compressed air from said at least one high-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,
- (d) variably closing said at least one first engine valve,
- (e) expanding said compressed air in said cylinder chamber during a second part of said volume-increasing stroke,

- (f) variably opening said at least one second engine valve,
  - (g) substantially displacing the air from said cylinder chamber into said at least one medium-pressure manifold during said volume-decreasing stroke, and
  - (h) variably closing said at least one second engine valve,
- and wherein said performance of a hybrid two-stroke internal-combustion cycle in said at least one primary cylinder, during operation of said engine in said third propulsion mode, further comprises, during each two-stroke cycle, the steps of:
- (a) variably opening said at least one first engine valve,
  - (b) receiving compressed air into said cylinder chamber from said at least one medium-pressure manifold during a second part of said volume-decreasing stroke,
  - (c) variably closing said at least one first engine valve,
  - (d) compressing the air and the residual combustion gas in said cylinder chamber during a third part of said volume-decreasing stroke,
  - (e) adding fuel to the mixture of said air and said residual combustion gas in said cylinder chamber,
  - (f) initiating combustion of said fuel in said cylinder chamber, whereby said fuel and said air are converted into a combustion gas,
  - (g) expanding said combustion gas in said cylinder chamber during said volume-increasing stroke,
  - (h) variably opening said at least one second engine valve,
  - (i) substantially expelling said combustion gas from said cylinder chamber into said at least one exhaust manifold during a first part of said volume-decreasing stroke, and
  - (j) variably closing said at least one second engine valve,
- whereby receiving of said compressed air into said cylinder chamber from said at least one medium-pressure manifold reduces the amount of compression work required.

33. The method of claim 28 wherein the operation of said engine in said fourth propulsion mode further includes the step of operating said engine as a conventional internal-combustion engine receiving air from said at least one low-pressure manifold into said cylinder chamber through said at least one first engine valve in said at least one primary cylinder and through at least one first engine valve in said at least one secondary cylinder,

and discharging exhaust gas from said cylinder chamber into said at least one exhaust manifold through said at least one second engine valve in said at least one primary cylinder and through at least one second engine valve in said at least one secondary cylinder.

34. The method of claim 11 wherein the step of providing said valves further comprises the steps of:

- (a) providing at least one first primary air valve for selectively and variably connecting said cylinder chamber in said primary cylinder to said at least one low-pressure manifold,
- (b) providing at least one second primary air valve for selectively and variably connecting said cylinder chamber in said primary cylinder to said at least one medium-pressure manifold,
- (c) providing at least one first secondary air valve for selectively and variably connecting said cylinder chamber in said secondary cylinder either to said at least one low-pressure manifold or to said at least one high-pressure manifold
- (d) providing at least one second secondary air valve for selectively and variably connecting said cylinder chamber in said secondary cylinder to said at least one medium-pressure manifold,
- (e) providing at least one exhaust valve for selectively connecting said cylinder chamber in each engine cylinder to said at least one exhaust manifold, and
- (f) providing a switching means for setting an arrangement of said gas exchange controlling means into a configuration selected from a variety of configurations, and switching said arrangement from one configuration to another in accordance with said program incorporated in said control means, said variety of configurations including:
  - (1) a first switching configuration wherein said at least one low-pressure manifold is connected to said at least one first primary air valve in said at least one primary cylinder, said at least one medium-pressure manifold is connected to said at least one second primary air valve in said at least one primary cylinder and to said at least one second secondary air valve in said at least one secondary cylinder, and said at least one high-pressure manifold is connected to said at least one first secondary air valve in said at least one secondary cylinder, and

- (2) a second switching configuration wherein said at least one low-pressure manifold is connected to said at least one first primary air valve in said at least one primary cylinder and to said at least one first secondary air valve in said at least one secondary cylinder, said at least one medium-pressure manifold is connected to said at least one second primary air valve in said at least one primary cylinder and to said at least one second secondary air valve in said at least one secondary cylinder, and said at least one high-pressure manifold is disconnected from said at least one first secondary air valve in said at least one secondary cylinder.
35. The method of claim 34 wherein said arrangement of said gas exchange controlling means is set into said second switching configuration if said engine operates in said fourth propulsion mode, and is set into said first switching configuration if said engine operates in any one of the following modes:
- (a) compression-braking mode,
  - (b) first propulsion mode,
  - (c) second propulsion mode, and
  - (d) third propulsion mode.
36. The method of claim 35 wherein a first air compression performed in said at least one primary cylinder, during operation of said engine in said compression-braking mode, further comprises, during each two-stroke cycle, the steps of:
- (a) deactivating said fuel delivery means,
  - (b) deactivating said at least one exhaust valve,
  - (c) expanding the residual compressed air during a first part of said volume-increasing stroke,
  - (d) variably opening said at least one first primary air valve,
  - (e) receiving air from said at least one low-pressure manifold into said cylinder chamber during a second part of said volume-increasing stroke,
  - (f) variably closing said at least one first primary air valve,
  - (g) compressing said air in said cylinder chamber during a first part of said volume-decreasing stroke,

- (h) variably opening said at least one second primary air valve,
  - (i) substantially displacing the compressed air from said cylinder chamber into said at least one medium-pressure manifold during a second part of said volume-decreasing stroke, and
  - (j) variably closing said at least one second primary air valve,
- and wherein a second air compression performed in said at least one secondary cylinder, during operation of said engine in said compression-braking mode, further comprises, during each two-stroke cycle, the steps of:
- (a) deactivating said fuel delivery means,
  - (b) deactivating said at least one exhaust valve,
  - (c) expanding the residual compressed air during a first part of said volume-increasing stroke,
  - (d) variably opening said at least one second secondary air valve,
  - (e) receiving air from said at least one medium-pressure manifold into said cylinder chamber during a second part of said volume-increasing stroke,
  - (f) variably closing said at least one second secondary air valve,
  - (g) compressing said air in said cylinder chamber during a first part of said volume-decreasing stroke,
  - (h) variably opening said at least one first secondary air valve,
  - (i) substantially displacing the compressed air from said cylinder chamber into said at least one high-pressure manifold, and
  - (j) variably closing said at least one first secondary air valve.

37. The method of claim 35 wherein a first stage of air expansion performed in said at least one secondary cylinder, during operation of said engine in said first propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said fuel delivery means,
- (b) deactivating said at least one exhaust valve,
- (c) variably opening said at least one first secondary air valve,
- (d) receiving compressed air from said at least one high-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,

- (e) variably closing said at least one first secondary air valve,
  - (f) expanding said compressed air in said cylinder chamber during a second part of said volume-increasing stroke,
  - (g) variably opening said at least one second secondary air valve,
  - (h) substantially displacing the air from said cylinder chamber into said at least one medium-pressure manifold during said volume-decreasing stroke, and
  - (i) variably closing said at least one second secondary air valve,
- and wherein a second stage of air expansion performed in said at least one primary cylinder, during operation of said engine in said first propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said fuel delivery means,
- (b) deactivating said at least one first primary air valve,
- (c) variably opening said at least one second primary air valve,
- (d) receiving air from said at least one medium-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,
- (e) variably closing said at least one second primary air valve,
- (f) expanding said air in said cylinder chamber during a second part of said volume-increasing stroke,
- (g) variably opening said at least one exhaust valve,
- (h) substantially displacing the air from said cylinder chamber into said at least one exhaust manifold during said volume-decreasing stroke, and
- (i) variably closing said at least one exhaust valve.

38. The method of claim 35 wherein said performance of a two-stroke air-motor cycle in said at least one secondary cylinder, during operation of said engine in said second propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said fuel delivery means,
- (b) deactivating said at least one exhaust valve,
- (c) variably opening said at least one first secondary air valve,
- (d) receiving compressed air from said at least one high-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,

- (e) variably closing said at least one first secondary air valve,
  - (f) expanding said compressed air in said cylinder chamber during a second part of said volume-increasing stroke,
  - (g) variably opening said at least one second secondary air valve,
  - (h) substantially displacing the air from said cylinder chamber into said at least one medium-pressure manifold during said volume-decreasing stroke, and
  - (i) variably closing said at least one second secondary air valve,
- and wherein said performance of a hybrid four-stroke cycle in said at least one primary cylinder, during operation of said engine in said second propulsion mode, further comprises, during each four-stroke cycle, the steps of:
- (a) deactivating said at least one first primary air valve,
  - (b) variably opening said at least one second primary air valve,
  - (c) receiving air into said cylinder chamber from said at least one medium-pressure manifold during a first part of a first volume-increasing stroke,
  - (d) variably closing said at least one second primary air valve,
  - (e) expanding said air in said cylinder chamber during a second part of said first volume-increasing stroke,
  - (f) compressing said air in said cylinder chamber during a first volume-decreasing stroke,
  - (g) adding fuel to said air,
  - (h) initiating combustion of said fuel in said cylinder chamber, whereby said fuel and said air are converted into a combustion gas,
  - (i) expanding said combustion gas in said cylinder chamber during a second volume-increasing stroke,
  - (j) variably opening said at least one exhaust valve,
  - (k) substantially expelling said combustion gas from said cylinder chamber into said at least one exhaust manifold during a first part of a second volume-decreasing stroke,
  - (l) variably closing said at least one exhaust valve, and
  - (m) trapping the residual combustion gas remaining in said cylinder chamber during a second part of said second volume-decreasing stroke,
- whereby work performed by said combustion gas during said second volume-increasing stroke is supplemented by work performed by said air during said first volume-increasing

stroke, and whereby trapping said residual gas in said cylinder chamber during said second part of said second volume-decreasing stroke contributes to reduction in harmful nitrogen oxide emission.

39. The method of claim 35 wherein said performance of a two-stroke air-motor cycle in said at least one secondary cylinder, during operation of said engine in said third propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said fuel delivery means,
- (b) deactivating said at least one exhaust valve,
- (c) variably opening said at least one first secondary air valve,
- (d) receiving compressed air from said at least one high-pressure manifold into said cylinder chamber during a first part of said volume-increasing stroke,
- (e) variably closing said at least one first secondary air valve,
- (f) expanding said compressed air in said cylinder chamber during a second part of said volume-increasing stroke,
- (g) variably opening said at least one second secondary air valve,
- (h) substantially displacing the air from said cylinder chamber into said at least one medium-pressure manifold during said volume-decreasing stroke, and
- (i) variably closing said at least one second secondary air valve,

and wherein said performance of a hybrid two-stroke internal-combustion cycle in said at least one primary cylinder, during operation of said engine in said third propulsion mode, further comprises, during each two-stroke cycle, the steps of:

- (a) deactivating said at least one first primary air valve,
- (b) variably opening said at least one second primary air valve,
- (c) receiving compressed air into said cylinder chamber from said at least one medium-pressure manifold during a second part of said volume-decreasing stroke,
- (d) variably closing said at least one second primary air valve,
- (e) compressing said compressed air and residual combustion gas in said cylinder chamber during a third part of said volume-decreasing stroke,
- (f) adding fuel to the mixture of said compressed air and said residual combustion gas in said cylinder chamber,



- (g) initiating combustion of said fuel in said cylinder chamber, whereby said fuel and said compressed air are converted into a combustion gas,
  - (h) expanding said combustion gas in said cylinder chamber during said volume-increasing stroke,
  - (i) variably opening said at least one exhaust valve,
  - (j) substantially expelling said combustion gas from said cylinder chamber during a first part of said volume-decreasing stroke, and
  - (k) variably closing said at least one exhaust valve,
- whereby receiving of said compressed air into said cylinder chamber from said at least one medium-pressure manifold reduces the amount of compression work required.

40. The method of claim 35 wherein the operation of said engine in said fourth propulsion mode further includes the step of operating said engine as a conventional internal-combustion engine receiving air from said at least one low-pressure manifold through said at least one first primary air valve into said at least one primary cylinder and through said at least one first secondary air valve into said at least one secondary cylinder, and discharging exhaust gas from said at least one primary cylinder and from said at least one secondary cylinder through said at least one exhaust valve in each cylinder into said at least one exhaust manifold.

41. The method of claim 10 wherein the step of providing said gas exchange controlling means further comprises the steps of:

- (a) providing a manifold means for accommodating gas flow into and out of said engine cylinders, said manifold means including:
  - (1) at least one low-pressure manifold,
  - (2) at least one medium-pressure manifold,
  - (3) at least one high-pressure manifold connected to said air-reservoir means, and
  - (4) at least one exhaust manifold,
- (b) providing valves for selectively, variably, and alternatively connecting said cylinder chamber to said manifold means in timed relation to said engine operation,

- (c) providing at least one turbocharger comprising a turbine that can be driven by gas expelled from said engine cylinders, and a compressor that can be driven by said turbine, said turbine having an inlet connected to said at least one exhaust manifold, and said compressor having an inlet connected to outside atmosphere, and
  - (d) providing a switching means for setting an arrangement of said at least one turbocharger connections to said manifold means into a configuration selected from a variety of configurations, and switching said arrangement of said at least one turbocharger connections from one configuration to another in accordance with said program incorporated in said control means, said variety of configurations including:
    - (1) a first turbocharger-switching configuration wherein an outlet from said turbine is connected to said at least one medium-pressure manifold, and an outlet from said compressor is connected to said at least one low-pressure manifold,
    - (2) a second turbocharger-switching configuration wherein said outlet from said turbine and said outlet from said compressor are connected to outside atmosphere, and
    - (3) a third turbocharger-switching configuration wherein said outlet from said turbine is connected to outside atmosphere, and said outlet from said compressor is connected to said at least one low-pressure manifold.
42. The method of claim 41 wherein said arrangement of said at least one turbocharger connections to said manifold means is set into:
- (a) said first turbocharger-switching configuration if said engine operates in said compression-braking mode,
  - (b) said second turbocharger-switching configuration if said engine operates in any one of the following modes:
    - (1) first propulsion mode,
    - (2) second propulsion mode, and
    - (3) third propulsion mode,and
  - (c) said third turbocharger-switching configuration if said engine operates in said fourth propulsion mode.

43. The method of claim 42 wherein:

- (a) the step of operating said engine in said compression-braking mode further comprises the steps of:
  - (1) receiving air from said outside atmosphere into said compressor, compressing said air in said compressor and displacing it into said at least one low-pressure manifold,
  - (2) receiving air from said at least one low-pressure manifold through at least one of said valves into said cylinder chamber in said at least one primary cylinder, compressing it in said at least one primary cylinder, displacing it from said at least one primary cylinder through another at least one of said valves into said at least one exhaust manifold, using it to drive said turbine, and depositing it into said at least one medium-pressure manifold, and
  - (3) receiving air from said at least one medium-pressure manifold through at least one of said valves into said cylinder chamber in said at least one secondary cylinder, compressing it in said at least one secondary cylinder, and displacing it from said at least one secondary cylinder through another at least one of said valves into said at least one high-pressure manifold,
- (b) operation of said engine in said first propulsion mode further comprises the steps of:
  - (1) receiving compressed air from said at least one high-pressure manifold through at least one of said valves into said cylinder chamber in said at least one secondary cylinder, expanding it in said at least one secondary cylinder, and displacing it from said at least one secondary cylinder through another at least one of said valves into said at least one medium-pressure manifold, and
  - (2) receiving air from said at least one medium-pressure manifold through at least one of said valves into said cylinder chamber in said at least one primary cylinder, expanding it and displacing it from said at least one primary cylinder through another at least one of said valves into said at least one exhaust manifold,
- (c) operation of said engine in said second propulsion mode further comprises the steps of:
  - (1) receiving compressed air from said at least one high-pressure manifold through at least one of said valves into said cylinder chamber in said at least one secondary cylinder, expanding it in said secondary cylinder, and displacing it from said

- secondary cylinder through another at least one of said valves into said at least one medium-pressure manifold, and
- (2) receiving air from said at least one medium-pressure manifold through at least one of said valves into said cylinder chamber in said primary cylinder, expanding it and using it for combustion in a four-stroke internal-combustion cycle performed in said at least one primary cylinder, and displacing said combustion gas from said at least one primary cylinder through another at least one of said valves into said at least one exhaust manifold,
- (d) operation of said engine in said third propulsion mode further comprises the steps of:
- (1) receiving compressed air from said at least one high-pressure manifold through at least one of said valves into said cylinder chamber in said at least one secondary cylinder, expanding it in said secondary cylinder, and displacing it from said secondary cylinder through another at least one of said valves into said at least one medium-pressure manifold, and
- (2) receiving air from said at least one medium-pressure manifold through at least one of said valves into said cylinder chamber in said primary cylinder, using it for combustion in a two-stroke internal-combustion cycle performed in said at least one primary cylinder, and displacing said combustion gas from said at least one primary cylinder through another at least one of said valves into said at least one exhaust manifold, and
- (e) operation of said engine in said fourth propulsion mode further comprises the steps of:
- (1) receiving air from said outside atmosphere into said compressor, compressing said air in said compressor and displacing it into said at least one low-pressure manifold,
- (2) receiving air from said at least one low-pressure manifold through at least one of said valves into each cylinder chamber in said at least two cylinders, using said air to perform a four-stroke internal-combustion cycle in said at least two cylinders, and exhausting combustion gas from each cylinder chamber in said at least two cylinders through another at least one of said valves into said at least one exhaust manifold, and
- (3) using said combustion gas to drive said turbine.

44. A method of operating a wheeled vehicle, said method comprising the steps of:
- (a) providing a piston-type engine mounted in said vehicle and coupled to at least one vehicle wheel for its propulsion and braking, said engine including at least one primary cylinder and at least one secondary cylinder,
  - (b) providing an air-reservoir means mounted in said vehicle and connected to said piston-type engine for receiving, storage, and discharge of compressed air,
  - (c) providing a control means for controlling the operation of said engine and said vehicle in response to driver's demands,
  - (d) providing a gas exchange controlling means for accommodating gas flow into, out of, and between said at least one primary cylinder and said at least one secondary cylinder,
  - (e) providing a fuel delivery means for selectively and variably adding fuel to the air intended for participation in combustion,
  - (f) operating said piston-type engine in a compression-braking mode driven by a vehicle momentum, in response to a vehicle driver's demand for a vehicle braking force, by repeatedly performing a first compression of air in said at least one primary cylinder and repeatedly performing a second compression of said air in said at least one secondary cylinder,  
said first compression of air comprising the steps of:
    - (1) receiving air from outside atmosphere into said at least one primary cylinder,
    - (2) compressing said air in said at least one primary cylinder, and
    - (3) expelling compressed air from said at least one primary cylinder,and said second compression of said air comprising the steps of:
    - (1) receiving said compressed air into said at least one secondary cylinder,
    - (2) further compressing said compressed air in said at least one secondary cylinder,
    - (3) expelling said compressed air from said at least one secondary cylinder, and
    - (4) receiving said compressed air into said air-reservoir means for storage therein,whereby energy of the vehicle motion is transformed into energy of compressed air stored in said air-reservoir means,
  - (g) using said energy of compressed air stored in said air-reservoir means to provide a compressed-air assist in said vehicle propulsion in response to vehicle driver's demand for a vehicle propulsion force,

- (h) operating said piston-type engine in a conventional internal-combustion mode when said energy of compressed air is not available, and
- (i) using said control means to control the magnitude of said vehicle braking force and of said vehicle propulsion force.

45. A system for operating a wheeled vehicle, said system comprising:

- (a) a piston-type engine mounted in said vehicle and coupled to at least one vehicle wheel for its propulsion and braking,
- (b) an air-reservoir means mounted in said vehicle and connected to said piston-type engine for receiving, storage, and discharge of compressed air,
- (c) at least one primary cylinder in said piston-type engine for receiving air from outside atmosphere and performing a first compression of said air during operation in a compression-braking mode,
- (d) at least one secondary cylinder in said piston-type engine for receiving air from said at least one primary cylinder, performing a second compression of said air, and displacing said air into said air-reservoir means during operation in said compression-braking mode,
- (e) a control means for controlling the operation of said engine and said vehicle in response to driver's demands,
- (f) a gas exchange controlling means for accommodating gas flow into, out of, and between said at least one primary cylinder and said at least one secondary cylinder, said gas exchange controlling means including at least one low-pressure manifold connected to outside atmosphere, at least one medium-pressure manifold, and at least one high-pressure manifold connected to said air-reservoir means, and
- (g) a fuel delivery means for selectively and variably adding fuel to the air intended for participation in combustion.

46. A method of operating a wheeled vehicle, said method comprising the steps of:

- (a) providing an engine mounted in said vehicle and coupled to at least one vehicle wheel for its propulsion and braking, said engine including:
  - (1) at least one cylinder,

- (2) a cylinder chamber within said at least one cylinder,
- (3) a head mounted to said at least one cylinder, and
- (4) a piston within each said cylinder chamber, with the piston to head and cylinder relationship being such that the volume of said cylinder chamber shrinks during a volume-decreasing stroke, when said piston moves toward said head, and expands during a volume-increasing stroke, when said piston moves away from said head,
- (b) providing an air-reservoir means mounted in said vehicle and connected to said engine for receiving, storage, and discharge of compressed air,
- (c) providing a control means for controlling the operation of said engine and said vehicle in response to driver's demands and in accordance with a control program incorporated in said control means,
- (d) providing a gas exchange controlling means for accommodating gas flow into and out of said cylinder chamber, said gas exchange controlling means comprising:
  - (1) a manifold means for accommodating gas flow into and out of said at least one cylinder, said manifold means including at least one low-pressure manifold, at least one medium-pressure manifold connected to said air-reservoir means, and at least one exhaust manifold,
  - (2) valves for selectively, variably, and alternatively connecting said cylinder chamber to said manifold means in timed relation to said engine operation,
  - (3) at least one turbocharger comprising a turbine that can be driven by gas expelled from said engine cylinders, and a compressor that can be driven by said turbine, said turbine having an inlet connected to said at least one exhaust manifold, and said compressor having an inlet connected to outside atmosphere, and
  - (4) a switching means for setting an arrangement of said at least one turbocharger connections to said manifold means into a configuration selected from a variety of configurations, and switching said arrangement of said at least one turbocharger connections from one configuration to another in accordance with said program incorporated in said control means, said variety of configurations including:
    - I. A first turbocharger-switching configuration wherein an outlet from said turbine is connected to said at least one medium-pressure manifold, and an outlet from said compressor is connected to said at least one low-pressure manifold,

II. A second turbocharger-switching configuration wherein said outlet from said turbine and said outlet from said compressor are connected to outside atmosphere, and

III. A third turbocharger-switching configuration wherein said outlet from said turbine is connected to outside atmosphere, and said outlet from said compressor is connected to said at least one low-pressure manifold.

- (e) providing a fuel delivery means for selectively and variably adding fuel to the air intended for participation in combustion in said engine in timed relation to said engine operation,
- (f) providing means for allowing a vehicle driver to perform vehicle control functions including:
  - (1) selectively demanding a vehicle braking force,
  - (2) selectively demanding a vehicle propulsion force,
  - (3) selectively demanding a change in magnitude of said vehicle braking force, and
  - (4) selectively demanding a change in magnitude of said vehicle propulsion force,
- (g) setting said arrangement of said at least one turbocharger connections to said manifold means into said first turbocharger-switching configuration and operating said engine in a compression-braking mode driven by a vehicle momentum in response to a demand for a vehicle braking force, when said vehicle is in motion, by repeatedly performing a two-stroke compressor cycle in said at least one cylinder, during which a charge of air is received from said compressor into said cylinder chamber, compressed therein, substantially displaced from said cylinder chamber, used to drive said turbine, and substantially displaced into said air-reservoir means for storage therein, whereby energy of the vehicle motion is transformed into energy of compressed air stored in said air-reservoir, and
- (h) operating said engine in a prime mover mode propelling said vehicle in response to said demand for a vehicle propulsion force, said prime mover mode including:
  - (A) operating said engine in a mode selected from a variety of propulsion modes comprising:
    - (1) a first propulsion mode including setting said arrangement of said at least one turbocharger connections to said manifold means into said second turbocharger-



switching configuration and repeated performance of a two-stroke air-motor cycle in said at least one cylinder, during which a compressed-air charge received from said air-reservoir means expands in said cylinder chamber during said volume increasing stroke, whereby said vehicle is propelled without any fuel being consumed,

- (2) a second propulsion mode including setting said arrangement of said at least one turbocharger connections to said manifold means into said second turbocharger-switching configuration and repeated performance of a hybrid four-stroke cycle in said at least one cylinder, said hybrid four-stroke cycle comprising two power strokes:
    - a first power stroke including expansion of a compressed-air charge, received from said air-reservoir means, in said cylinder chamber during a first volume increasing stroke, and
    - a second power stroke including expansion of combustion gas produced as a result of fuel combustion in said cylinder chamber during a second volume increasing stroke,
  - (3) a third propulsion mode including setting said arrangement of said at least one turbocharger connections to said manifold means into said second turbocharger-switching configuration and repeated performance of a hybrid two-stroke internal combustion cycle in said at least one cylinder during which a compressed-air charge is received into said cylinder chamber from said air-reservoir means and used for combustion during the same cycle, whereby energy of said compressed-air charge supplements the energy released in combustion, and
  - (4) a fourth propulsion mode including setting said arrangement of said at least one turbocharger connections to said manifold means into said third turbocharger-switching configuration and operating said engine in a conventional turbocharged internal-combustion mode receiving air from said outside atmosphere via said compressor, and
- (B) changing said engine operation from one propulsion mode to another one selected from said variety of propulsion modes.

47. The method of claim 46 wherein:

- (a) the step of operating said engine in said compression-braking mode further comprises the steps of:
  - (1) receiving air from said outside atmosphere into said compressor, compressing said air in said compressor and displacing it into said at least one low-pressure manifold,
  - (2) receiving air from said at least one low-pressure manifold through at least one of said valves into said cylinder chamber, further compressing it in said cylinder chamber, displacing it from said cylinder chamber through another at least one of said valves into said at least one exhaust manifold, using it to drive said turbine, and depositing it into said at least one medium-pressure manifold, and
  - (3) transferring said air from said at least one medium-pressure manifold into said air-reservoir means,
- (b) operation of said engine in said first propulsion mode further comprises the steps of receiving compressed air from said at least one medium-pressure manifold through at least one of said valves into said cylinder chamber, expanding it in said cylinder chamber, and displacing it from said cylinder chamber through another at least one of said valves into said at least one exhaust manifold,
- (c) operation of said engine in said second propulsion mode further comprises the steps of receiving air from said at least one medium-pressure manifold through at least one of said valves into said cylinder chamber, expanding it and using it for combustion in a four-stroke internal-combustion cycle performed in said cylinder chamber, and displacing combustion gas from said cylinder chamber through another at least one of said valves into said at least one exhaust manifold,
- (d) operation of said engine in said third propulsion mode further comprises the steps of receiving air from said at least one medium-pressure manifold through at least one of said valves into said cylinder chamber, using it for combustion in a two-stroke internal-combustion cycle performed in said cylinder chamber, and displacing combustion gas from said cylinder chamber through another at least one of said valves into said at least one exhaust manifold, and
- (e) operation of said engine in said fourth propulsion mode further comprises the steps of:

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- (1) receiving air from said outside atmosphere into said compressor, compressing said air in said compressor and displacing it into said at least one low-pressure manifold,
- (2) receiving air from said at least one low-pressure manifold through at least one of said valves into said cylinder chamber, using said air to perform a four-stroke internal-combustion cycle in said cylinder chamber, and exhausting combustion gas from said cylinder chamber through another at least one of said valves into said at least one exhaust manifold, and
- (3) using said combustion gas to drive said turbine.